(12) UK Patent Application (19) GB (11) 2 370 128 (13) A

(43) Date of A Publication 19.06.2002

(21) Application No 0030258.8

(22) Date of Filing 12.12.2000

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(51) INT CL^{7}
G02B 6/10

(52) UK CL (Edition T)
G2J JGDBG

(56) Documents Cited
WO 98/39676 A1 US 5799118 A

(58) Field of Search
UK CL (Edition S) G2J JGDBG
INT CL^{7} G02B
Online: WPI, EPODOC, JAPIO

(54) Abstract Title
Arrayed waveguide grating with optical delay regions

(57) A waveguide array device comprising a plurality of array waveguides 12 is arranged such that any change in optical path lengths due to changes in temperature is substantially the same for each array waveguide of the device. This is done by choosing appropriate optical delay regions for the waveguides so that, a device having a constant, or substantially constant, change of optical path length with temperature across all the waveguides can be achieved. A core of at least one of said waveguides includes at least one optical delay region 30 made of a material having a dn/dT of different magnitude but of the same sign as the dn/dT of the material used in the core of this waveguide outside of this optical delay region.

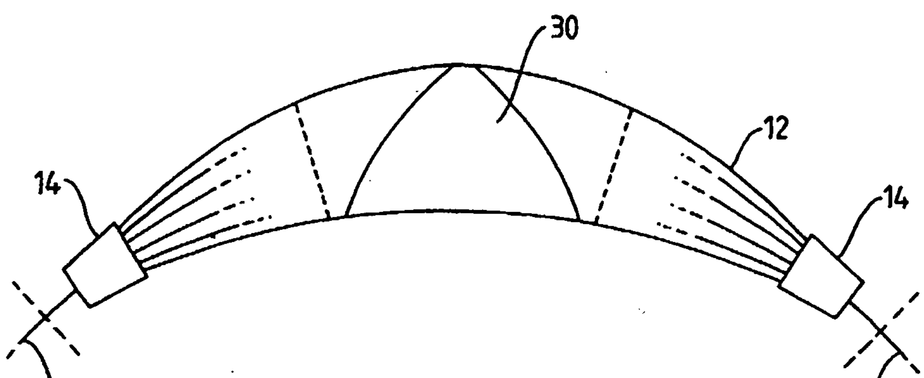

FIG. 5

GB 2 370 128 A

At least one drawing originally filed was informal ...

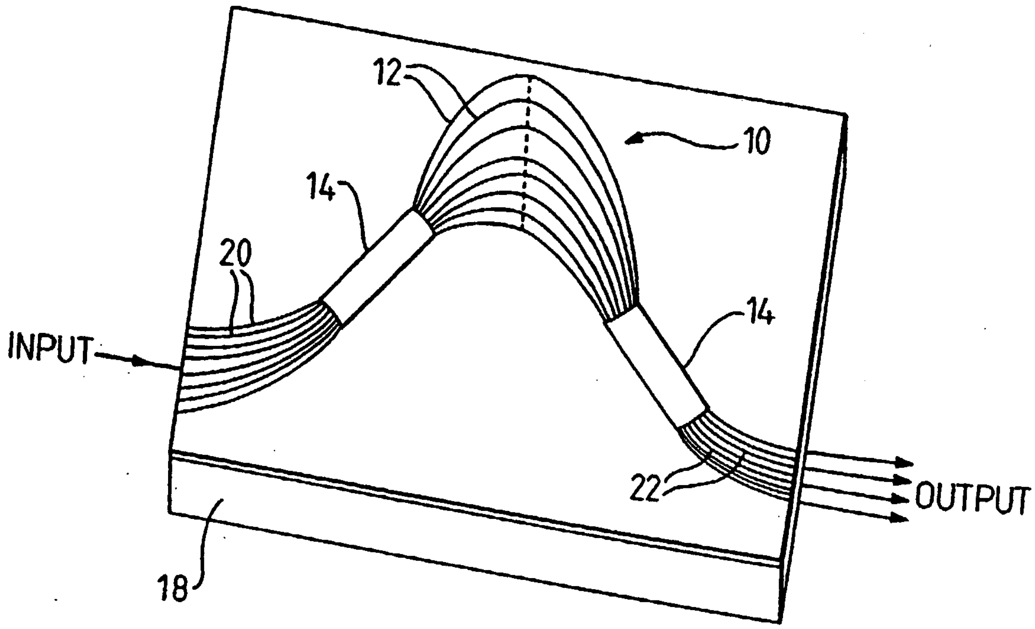
12
10
14
20
INPUT
14
22
OUTPUT
18

FIG. 1

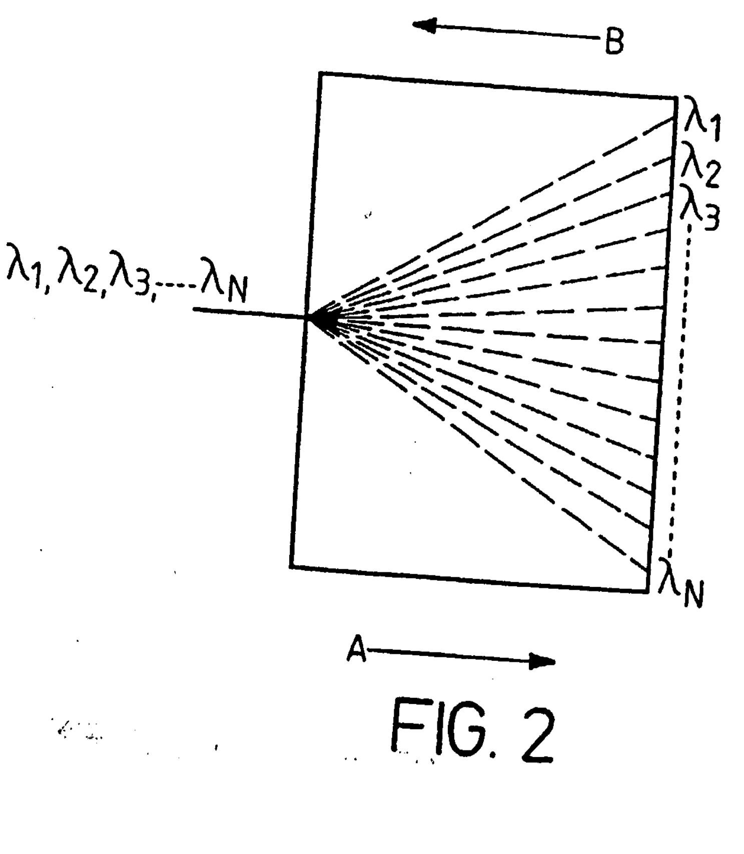
B
λ_1
λ_2
λ_3
$\lambda_1, \lambda_2, \lambda_3, \ldots \lambda_N$
λ_N
A

FIG. 2

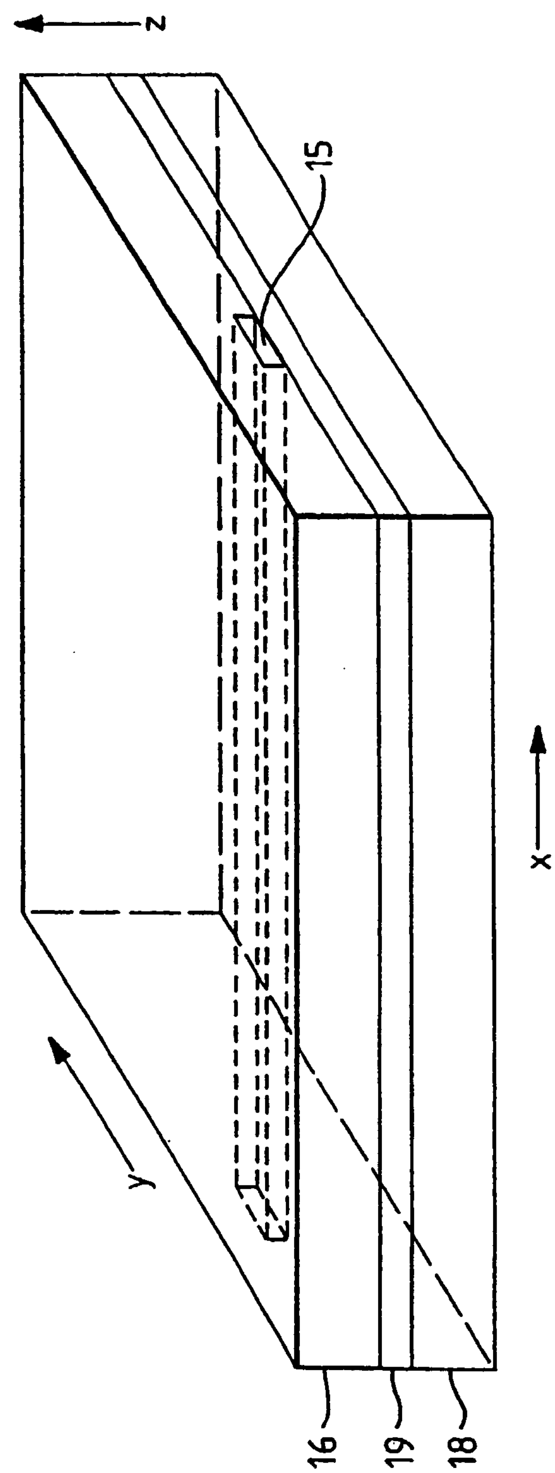

FIG. 3

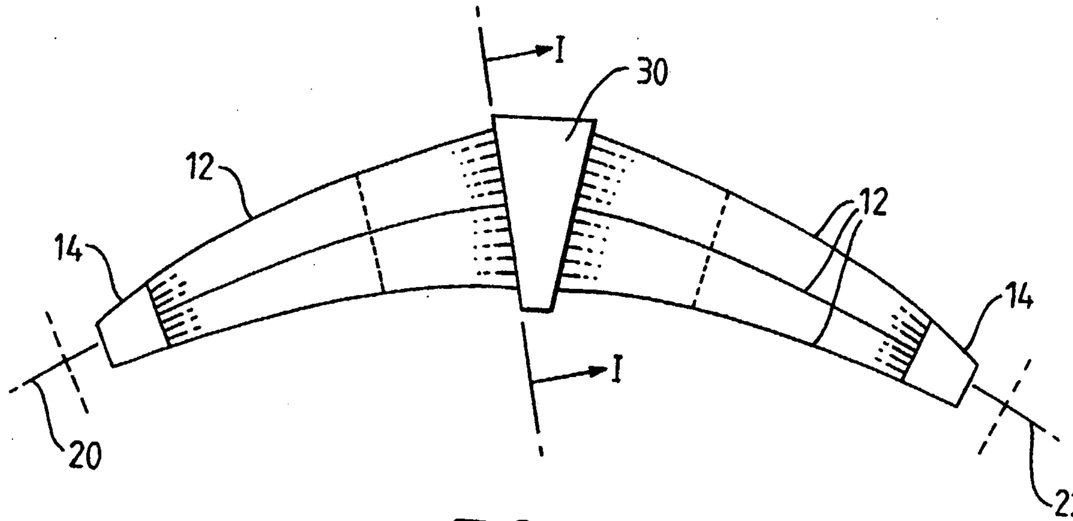

FIG. 4

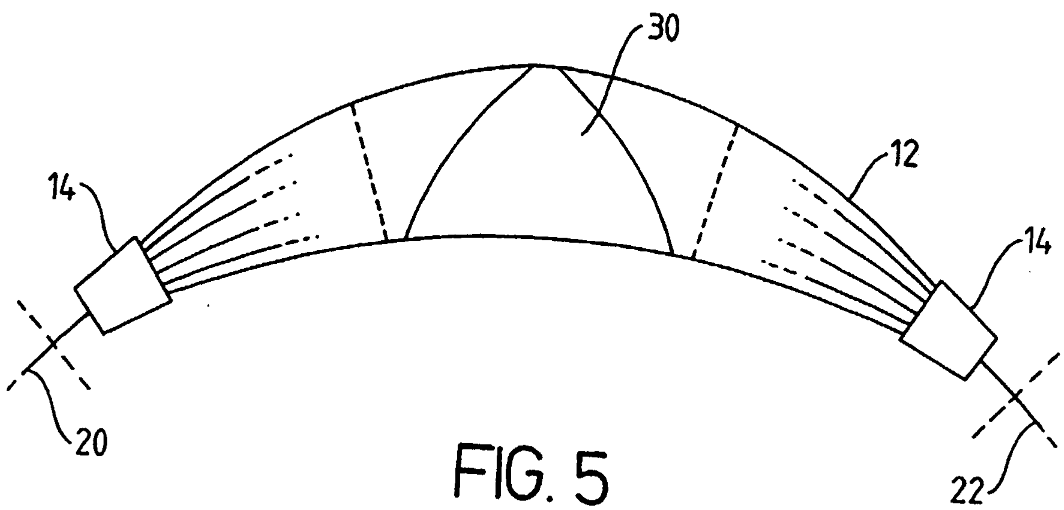

FIG. 5

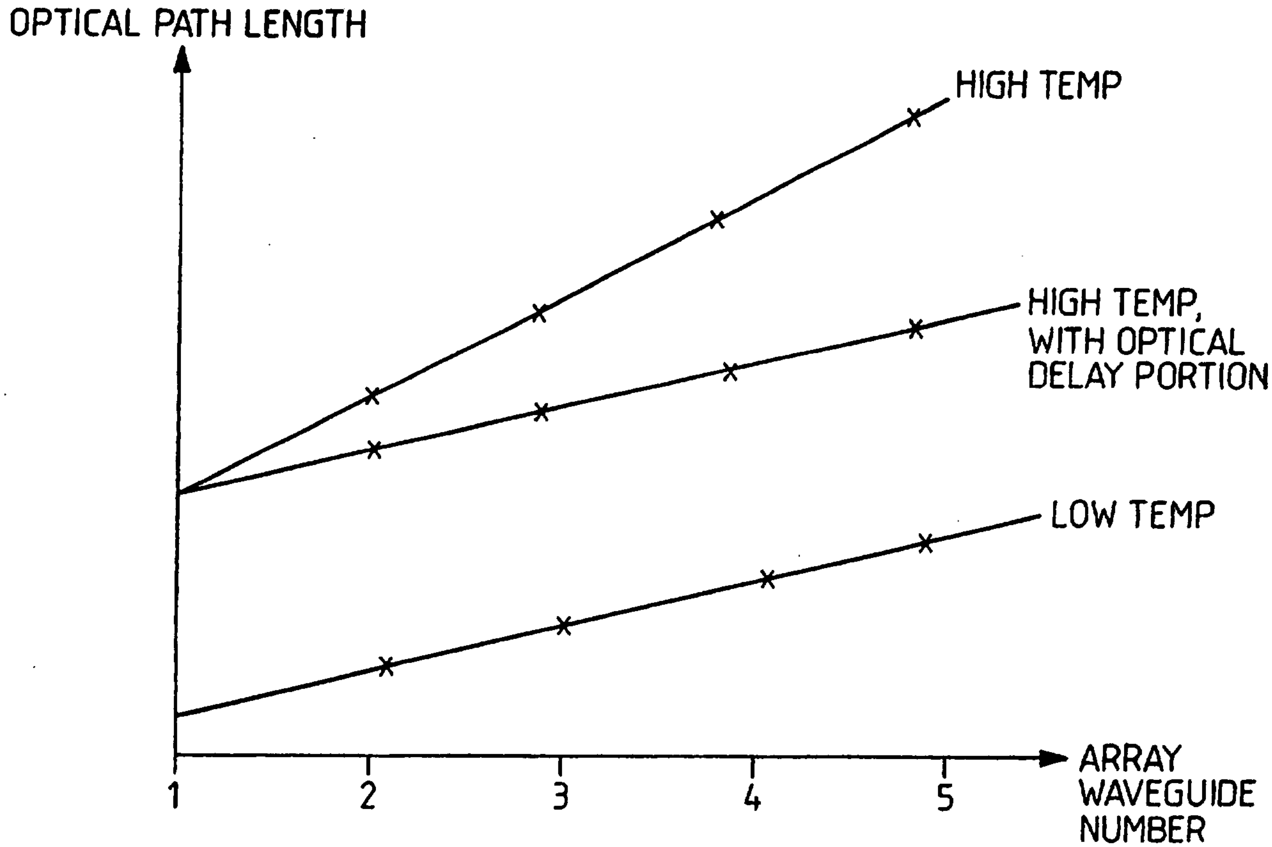
OPTICAL PATH LENGTH
HIGH TEMP
HIGH TEMP, WITH OPTICAL DELAY PORTION
LOW TEMP
1
2
3
4
5
ARRAY WAVEGUIDE NUMBER

FIG. 6

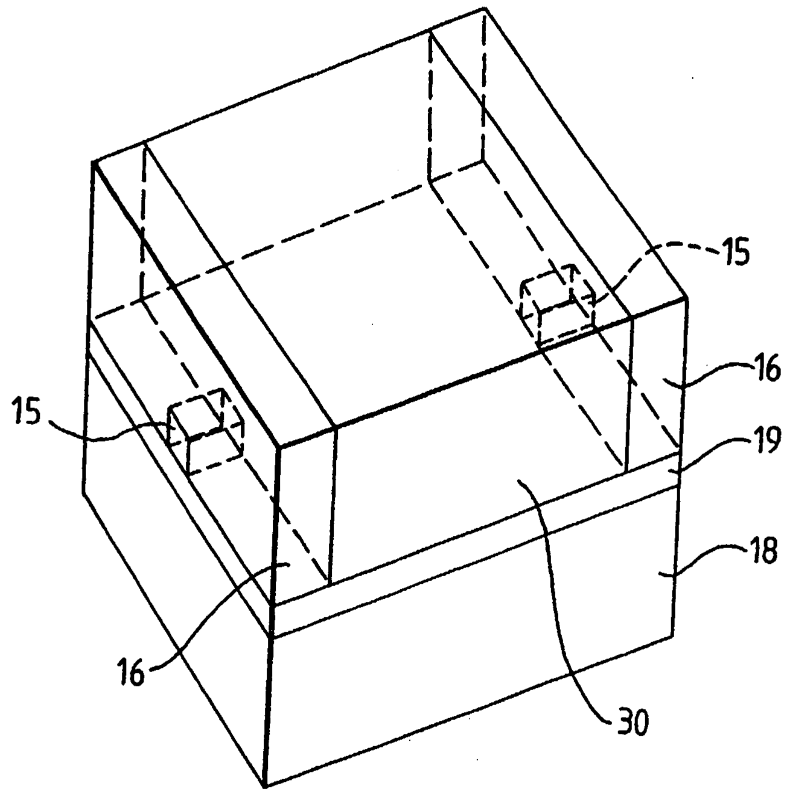

FIG. 7

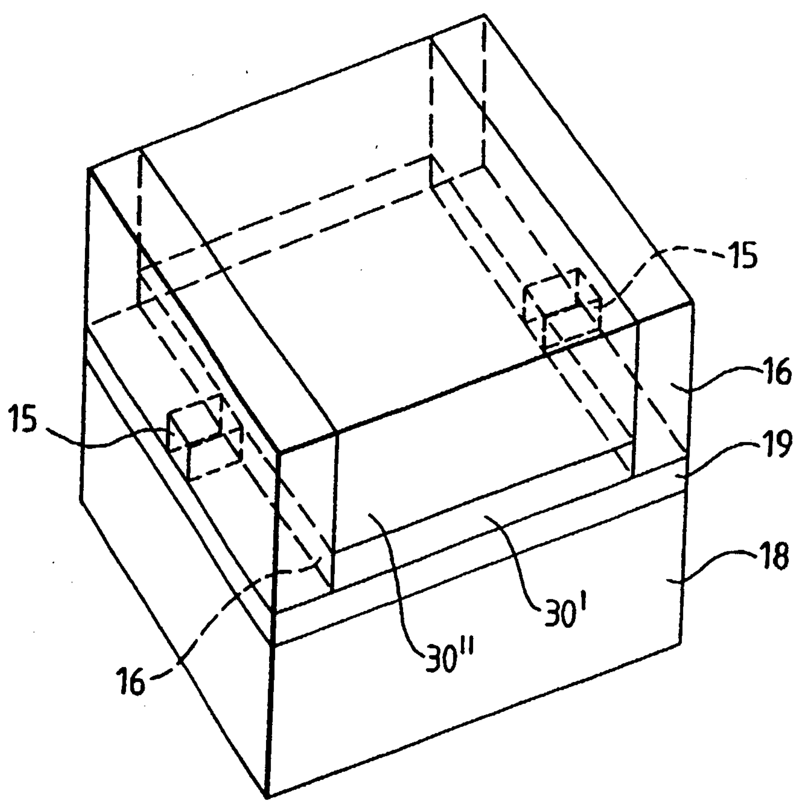

FIG. 8

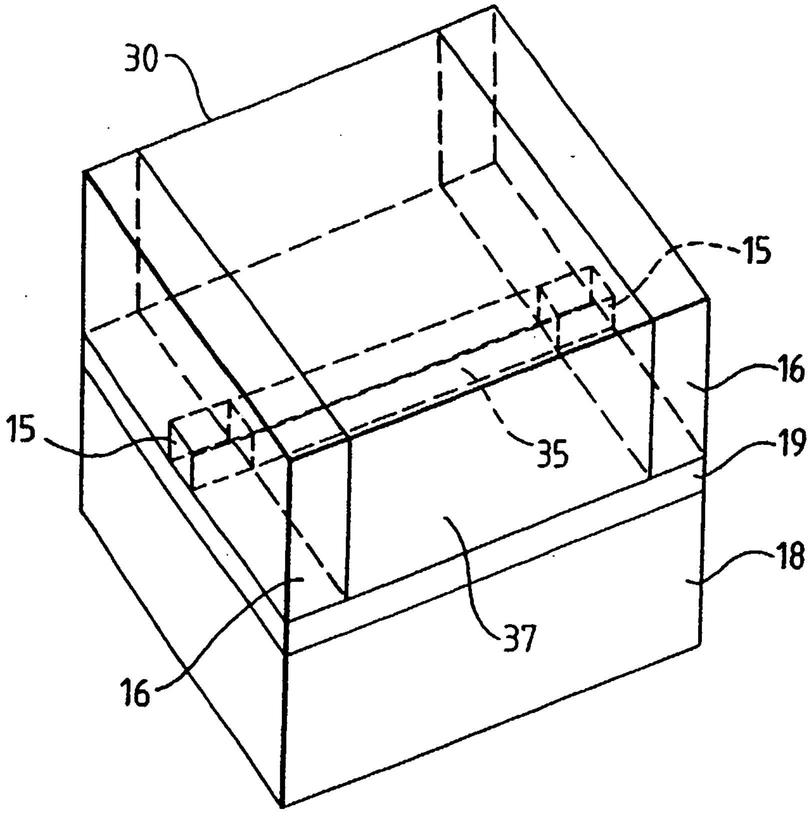

FIG. 9

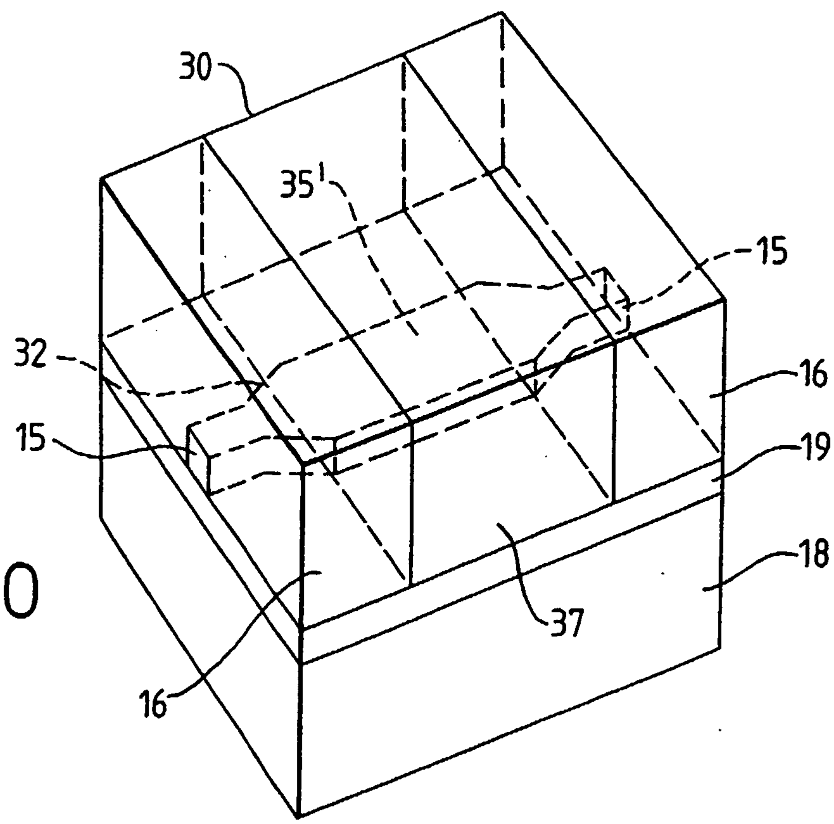

FIG. 10

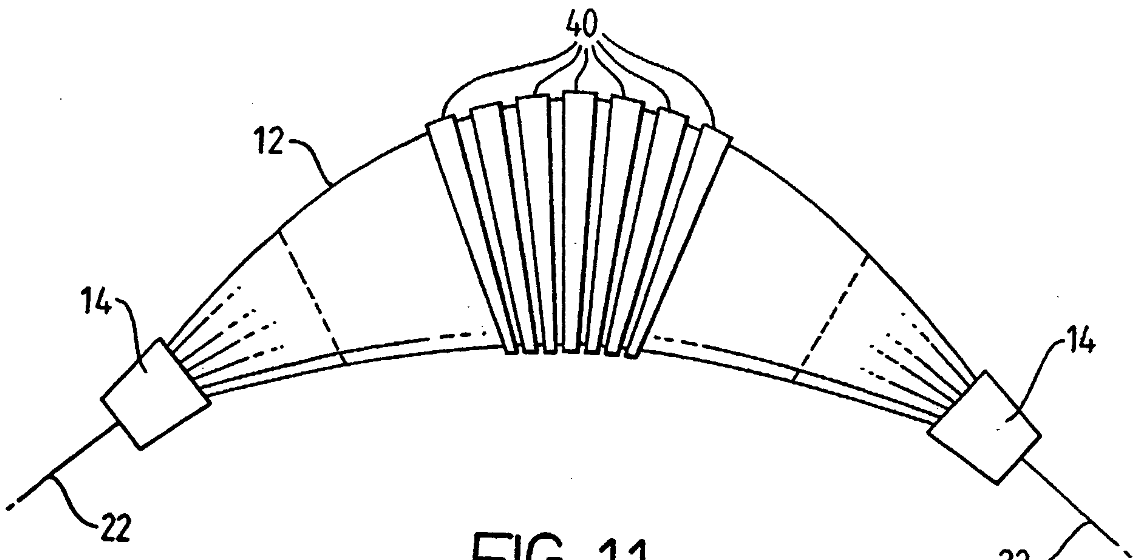

FIG. 11

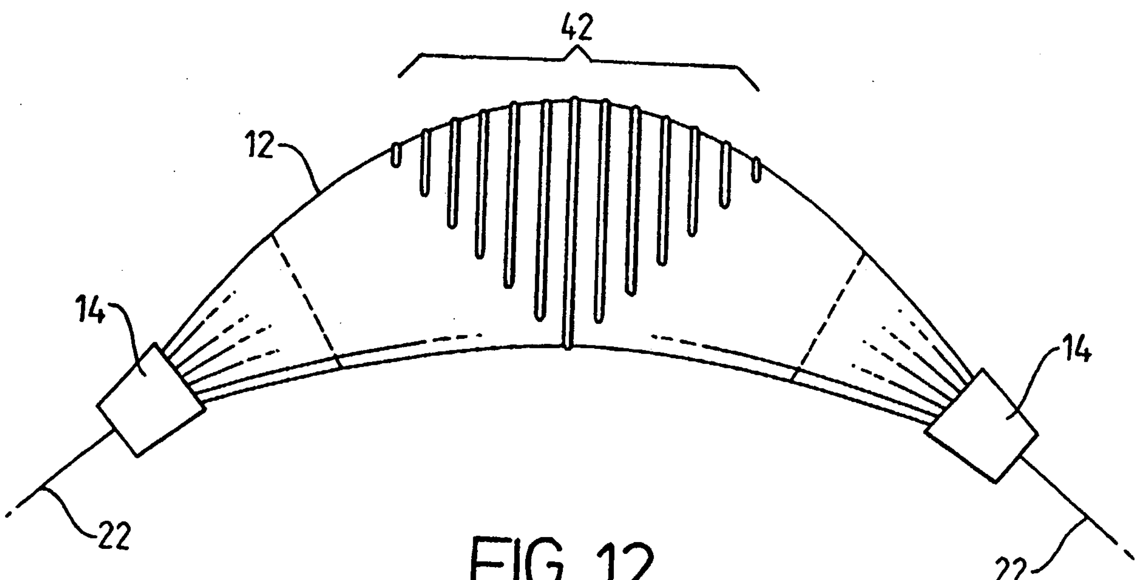

FIG. 12

OPTICAL DEVICES

The invention relates to optical devices and in particular to optical devices with low temperature dependence.

In order to meet the ever increasing demand for transmission bandwidth, which has been further fuelled by the recent internet explosion, operators are investing heavily in the development of techniques for Dense Wavelength Division Multiplexing. DWDM allows multiple wavelengths carrying separate data streams to be transmitted along a single optical fibre thus multiplying the available bandwidth by the number of wavelengths present. Early multiplexed systems deployed in 1996 used four different wavelengths. Current systems are now being shipped with 40 to 80 channels and even higher densities are under development.

In order to exploit the amplifier characteristics of erbium-doped fibre it is necessary to pack all of the wavelengths into a narrow band, around 30nm wide. A quick calculation shows that 80 channels corresponds to a channel separation of 0.4nm, or 50GHz. Clearly, to utilise this available bandwidth it is necessary to be able to separate, or de-multiplex, each channel at the receiver. Several techniques for doing this are available, such as the use of dichroic filters, Bragg gratings and, more recently, Arrayed Waveguide Gratings (AWG).

An Array Waveguide Grating is a planar structure comprising a number of arrayed channel waveguides which together act like a diffraction grating in a spectrometer. Such gratings have a high wavelength resolution, thus attaining narrow wavelength channel spacings down to as little as 0.2nm (25GHz) or lower in the ITU (International Telecommunications Union) channel allocation.

An AWG multiplexer is a device which combines optical signals of different wavelengths; conversely, an AWG demultiplexer splits a multiplexed signal into a plurality of signals. An AWG multiplexer typically comprises two focusing slab

regions, often called couplers, connected to either end of an arrayed waveguide grating, a plurality of input waveguides connected to one of the slab regions, and one or more output waveguide(s) connected to the other slab region. An AWG demultiplexer typically comprises two focusing slab regions connected to either end of an arrayed waveguide grating, one or more input waveguide(s) connected to one of the slab regions, and a plurality of output waveguides connected to the other slab region.

Since AWGs work in both directions, a multiplexer can often be used as a demultiplexer by using it in the reverse direction. The most flexible device is obtained by employing multiple input and output waveguides. The function of the device then depends on the nature of the signal, or signals, input to the device, that is whether the input is a multiplexed signal of many wavelengths or a plurality of single wavelength signals.

A typical AWG mux/demux, as shown in Fig. 1, comprises two optical interaction regions, in the form of two focusing slab regions 14, hereafter called couplers, connected to either end of an arrayed waveguide grating 10. The grating 10 consists of an array of channel waveguides 12, only some of which are shown. Input multiple WDM signals are dispersed and focused simultaneously to each prescribed output waveguide 22.

In the arrangement shown in Figure 1 a substrate 18 has formed on it first and second couplers 14, a plurality of array waveguides 12 a plurality of input/output waveguides 20 connected to the first coupler, and a plurality of input/output waveguides 22 connected to the second coupler. The array waveguides 12 and/or input/output waveguides 20, 22 are preferably arranged generally side-by-side.

Each of the waveguides 12, 20, 22, has a core 15 with a cladding material 16 at least on either side of it.

The couplers 14 are preferably star couplers, which are well known in the art, and which have curved input and output surfaces. The curve of the input/output of the

slabs enhances focusing of the signals, but also enables neighbouring waveguides to be angled away from each other in the vicinity of the coupler, thereby reducing the cross talk.

The waveguide array device preferably comprises an array 10 of waveguides 12 having different lengths, to provide an array of different path lengths to an input signal. Preferably the path length difference between neighbouring waveguides of the array is a constant, L where $L=m\lambda_c/n_c$ and λ_c is the central wavelength of the grating, n_c is the effective refractive index of the channel waveguides and m is an integer number. Light entering the launch end of the array undergoes differential phase shifting in each channel, proportional to its length, and emerges from the output end of the array to form a free-space diffraction pattern. The angular position of the peak of the diffraction pattern is related to the differential phase shift between adjacent waveguide channels. The grating acts as a phase grating of order m. Single mode channel waveguides are preferably used to enable exact phase control in the grating.

The arrangement works as follows. Light from an input waveguide expands as a 2D diverging wave inside the first slab and excites the input of the arrayed waveguide channels which start along a curve, in this example an arc of a circle with radius r, around the slab input. After travelling through the arrayed waveguides, the light at the end face of the grating, arranged on a circle with radius r, is radiated as a 2D wave into the second slab region as a converging wavefront and converges to a focal point at the slab exit where the outgoing waveguide is located.

The signal path length difference in the array 10 results in a wavelength dependent tilt of the radiated spherical wave, converging to a shifted focal point. The pitch of the channel waveguides at the grating exit is typically around 17μm.

This process is best understood by considering its analogy to a conventional diffraction grating. If the channels in the array were all of the same length then the situation would be identical to a conventional diffraction grating and the central intensity peak of the diffraction pattern would lie on the normal to the end face of the

array. Varying the wavelength of light launched into the array would cause the side-lobes of the diffraction pattern to move in a transverse direction but the central, dominant, peak would remain stationary. In order to improve the efficiency of diffraction gratings of the type used in spectroscopy it is usual to introduce a slight angle into each of the ruled lines on the grating. This process, known as 'blazing', causes the bulk of the light in the central peak to shift to one of the diffracted orders, resulting in a large increase of useful signal. The process of blazing is mimicked in the waveguide array by introducing a linear phase shift between each waveguide channel. This causes the zero-order diffraction peak to be at a large angle to the axis of the array but the bulk of the forward travelling light occurs in a useful diffraction order.

As the wavelength is varied, the angular position of the diffracted beam changes enabling the wavelength to be either measured or, in the case of a de-mulitplexer, to be isolated.

The wavelength resolution of the arrayed grating, $\Delta\lambda$, turns out to have the same expression as that for a conventional diffraction grating:

$$\Delta\lambda = \frac{\lambda}{Nm}$$

where: N is the number of channel waveuides in the array,
m is the diffraction order.

Thus for a high resolution a large number of channels and a large diffraction order are required.

Referring to the device shown schematically in Figure 2, for a signal transmitted in the direction of arrow 'A', the device comprises a single input waveguide and multiple output waveguides. The device functions as a demultiplexer, splitting an input signal of many wavelengths into a plurality of output signals, each of

a single wavelength. The same grating could function in reverse as a multiplexer, as shown by arrow 'B'.

The two main material systems used for the fabrication of AWG multiplexers are InGaAsP-InP and silica-on-silicon. Although the former has the advantage of direct integration with active devices, such as laser sources, the latter is becoming the material of choice for the fabrication of high quality, low-loss DWDM components. One of the main reasons for this is the lower temperature sensitivity of silica-based components, by about a factor of ten.

Even so, the temperature coefficient of wavelength selective devices manufactured in silica is approximately 0.012nm/°C. This corresponds to a frequency shift of about 45GHz over a temperature change of 30°C, which is often unacceptable.

Various mechanisms have been investigated to reduce this sensitivity, including active temperature stabilisation, overlays with negative index temperature coefficient, substrates with negative thermal expansion coefficient and multi-component waveguide structures. These mechanisms intend to eliminate the change in wavelength of optical waveguides with changes in temperature by counteracting the change in optical path length in the array waveguides caused by any change in temperature.

The applicant has appreciated that in many applications of Array Waveguide Grating devices, significant advantages can be obtained, instead of counteracting and thereby eliminating any change in optical path length of the array waveguides due to changes in temperature, by arranging the device so that the change in optical path length is the same for each array waveguide of the device.

Thus, according to the present invention there is provided a waveguide array device according to claim 1.

It will be appreciated that by choosing appropriate optical delay regions for the waveguides, a device having a constant, or substantially constant, change of optical path length with temperature across all the array waveguides can be achieved. For example, for waveguide cores made of material having a positive dn/dT, then by providing a region, in the path of the core, of material having larger magnitude, but still positive, dn/dT, with a longer such region (along the length of the waveguides) being provided in array waveguides of shorter length, this can assist in equalizing the change in optical path length for each array waveguide, with temperature change..

The invention is described in more detail in the appended claims to which reference should now be made.

Preferred embodiments of the invention will now be described with reference to the drawings in which:

Figure 1 shows the waveguide pattern of an AWG multi/demultiplexer chip;
Figure 2 shows schematically the function of an AWG multi/demultiplexer;
Figure 3 shows a schematic perspective of an optical substrate;
Figure 4 shows schematically a plan view of an optical device of the prior art;
Figure 5 shows schematically a schematically a plan view of an optical device according to an embodiment of the invention;

Figure 6 illustrates the temperature characteristic of the refractive index of array waveguides in AWGs;

Figure 7 is a perspective schematic view of a portion of the device of Fig.5;
Figure 8 is a perspective schematic view of a modified version of the device of Fig.7;

Figure 9 is a perspective schematic view of a modified version of the device of Fig.8;

Figure 10 is a perspective schematic view of a further modified version of the device of Fig.8;

Figure 11 shoes a modified version of the device of Fig.5; and
Figure 12 shows a further modified version of the device of Fig.5.

Figure 3 shows schematically how an optical waveguide is formed on a substrate. A silica waveguide is defined to consist of the following regions:

- a substrate 18 of silicon, SiO_2 (silica) or the like;
- a (possibly doped) silica buffer layer 19 deposited by thermal oxidation or by flame hydrolysis deposition or another method, and of course not required on a silica substrate;
- a (possibly doped) silica cladding layer 16 deposited by flame hydrolysis (FHD) or plasma enhanced chemical vapour deposition; and
- one or more (possibly doped) cores 15 surrounded by the cladding and buffer regions. The cores may be formed by laying down a layer of core glass by FHD and a consolidation step, then photolithographically masking and etching to form the core paths. The cladding and any other subsequent layers can then be established by FHD.

For the purpose of characterising an optical waveguide, the following parameters are defined:

$n_{substrate}$	substrate 18 refractive index
n_{buffer}	buffer 19 refractive index
n_{clad}	cladding 16 refractive index
n_{core}	core 15 refractive index
$t_{substrate}$	substrate 18 thickness
t_{buffer}	buffer 19 thickness
t_{clad}	cladding 16 thickness
t_{core}	core 15 thickness
W_{core}	core 15 width

A waveguide fabricated according to embodiments of the invention is defined to possess the following characteristics:

Refractive Index (RI)

$n_{core} > n_{clad}, n_{buffer}$

$n_{substrate} >> n_{bufffer}, n_{clad}, n_{core}$ (for Si substrate)

$n_{substrate} < n_{core}$ (for SiO_2 substrate)

Dimensions

$t_{substrate} >> t_{clad} + t_{buffer}$

$t_{clad}, t_{buffer} > t_{core}$

The present invention can be used in the context of the AWG mux/demux shown in Figure 1, and described earlier. Preferably, such an arrangement is provided as a planar silica-on-silicon integrated chip produced by FHD. However, other substrates may also be used. The present invention also finds application in many other optical devices.

Figure 4 shows an illustration of an "athermal" device of the prior art. In this a wedge-shaped region is etched through the waveguide array and filled with a negative dn/dT silicon adhesive. The wedge is wider at the outer edge of the curve providing a greater path length compensation to those waveguides providing greater optical path length. Such a wedge-shaped insert is used to minimise or substantially avoid any change in optical path length of each waveguide, despite changes in temperature.

Fig. 5 shows an Arrayed Waveguide Grating according to one embodiment of the invention, in which the array waveguides 12 are interrupted by an optical delay portion 30. The optical delay portion has a positive temperature coefficient dn/dT to provide an evening out across the array waveguides of the change in path length caused by a temperature change. The difference in the path length between each pair of adjacent waveguides of the array thus remains constant. The optical delay portion 30 is typically made of a high +dn/dT glass, such as a high boron doped silica material. The magnitude of the dn/dT of the glass is either larger or smaller than the magnitude of the dn/dT of the material of the cores of the waveguides (outside the optical delay portion).

The optimum shape of the optical delay portion 30 depends on a number of factors including the substrate and waveguide core and cladding materials used, the difference in path length between adjacent array waveguides etc., but will generally be wider, that is interrupt the array waveguides for a longer distance, in respect of the shorter waveguides of the array. For example, this will generally be the case where the material of the inserted optical delay portion has a larger magnitude dn/dT (but of the same sign) than the material of the core of the rest of the waveguide portions. Where instead the material of the optical delay portion has a smaller dn/dT (but of the same sign) than the material of the core of the rest of the waveguide portions then the optical delay portion will instead be narrower, that is interrupt the waveguides for a shorter distance, in respect of the shorter waveguides of the array (i.e. similar to the shape of the compensation portion of the prior art device of Fig.4).

The optical delay portion can be formed by masking and etching a planar arrayed waveguide device so as to etch a wedge-shaped groove through the array; then depositing a thin layer of the high boron doped glass in the groove. Fig.7 shows the optical delay portion 30 dividing a waveguide into two portions. The delay portion 30 thus effectively cuts through both the core and the cladding.

The function of the device according to the present invention will now be explained with reference to Figure 6, which shows a representation of the typical optical path lengths for a number of adjacent array waveguides at normal temperature and at a high temperature in a standard AWG and a AWG in an embodiment of the invention.

The lower curve represents the situation where the temperature is the device's optimum temperature. As can be seen by the straight line of this curve, there is a constant path length difference between adjacent array waveguides. At elevated temperature the waveguides increase in path length due to the change in refractive index with temperature (optical path length = nd, where n is the refractive index, and d is the physical path length). The amount by which the optical path length of the

waveguides increases, due to change in refractive index, is thus determined by the value of the coefficient dn/dT, where n is the refractive index of the waveguides.

Although at the higher temperature the difference in optical path length between adjacent waveguides is the same throughout the array, the magnitude of this difference in optical path length between adjacent waveguides has increased, as compared with the lower temperature case. This is illustrated in Fig.6, which plots optical path length against waveguide number (where the waveguides in the array are numbered 1,2,3,.., starting with the shortest length waveguide). The uppermost line in Fig.6 indicates the high temperature case and the lowermost line the low temperature case. The increased gradient of the graph in the high temperature case, as compared with the low temperature case, illustrates the increased path length difference between adjacent waveguides. This increase in the path length difference affects the output from the device in a detrimental manner. Any change in path length difference between adjacent waveguides affects the interference conditions in the device, thereby affecting the wavelength channel outputs of the device. This can affect the central (output) wavelength of the device, as well as the other output wavelengths.

The intermediate plot in the graph of Fig.6 illustrates the case for a device according to the invention, where an optical delay portion has been employed so as to equalize the change in optical path lengths of the array waveguides. This plot has the same gradient as for the low temperature case, indicating that the difference in optical path length between adjacent waveguides has not changed.

In the described embodiment, where the dn/dT of the material of the array waveguides is positive, it will be appreciated that material of the wedge-shaped insert in the device of Fig.5 is chosen to also have a positive dn/dT, but of greater magnitude, than the material used in the cores of the waveguides (outside the wedge-shaped insert).

Therefore, the widest end of the wedge is arranged to divide the shortest array waveguide, as shown in Fig.5. It will be appreciated the change in optical path length

of the longest waveguide is not avoided, but the wedge insert is used to ensure that all the other waveguides undergo substantially the same change in optical path length.

In an alternative embodiment of the invention, the material of the wedge-shaped insert is chosen to have a positive dn/dT, but of smaller magnitude than the material of the cores of the remaining portions of the waveguides, and the widest end of the wedge therefore divides the longest array waveguide.

In a further modification of the described embodiment, the optical delay portion may itself be formed from more than one layer of material. For example, in the embodiment illustrated in Fig.8, the optical delay portion comprises two layers, namely an upper "cladding" layer 30'' and a lower "guiding" layer 30'. The guiding layer is made of the material having a dn/dT of different magnitude, but of the same sign (+ve or –ve) as the core of the remaining portions of the waveguides. This "slab waveguide" type construction of the optical delay portion has the benefit of restricting spreading of light signals (passing though the optical delay portion) in the z-direction i.e. perpendicular to the plane of the AWG device. This reduces power loss in the light signals passing through the delay portion, as compared with the device of Fig.7. The upper cladding layer 30'' will generally be made of a different material to that of the cladding in the remaining portions of the waveguides, the chosen material being dependent on the material chosen for the guiding layer 30' (for example, the refractive index of the cladding layer 30'' needs to be less than the refractive index of the guiding layer 30' to ensure that the light signal is confined, or at least substantially confined, in the guiding layer 30').

Fig. 8 shows a further modified embodiment in which the optical delay portion is constructed to restrict spreading of light signals in two-dimensions. In this embodiment, the optical delay portion has a "core" region 35 and a "cladding" region 37, thus taking the form of a conventional waveguide, within the optical delay portion. The core region 35 is made of the material having a dn/dT of different magnitude, but of the same sign (+ve or –ve) as, the core of the remaining portions of the waveguides.

The core region 35 in the illustrated embodiment has the same dimensions as the core 15 in the remaining portions of the waveguides on either side thereof.

A further modified embodiment is shown in Fig. 10 in which the ends of the portions of the cores of the array waveguides 15 on either side of the optical delay portion 30 are tapered outwardly 32 to match wider core dimensions of the core region 35' in the optical delay portion 30. These tapers 32 shape the modes of the signal passing through the waveguides, to reduce divergence of the signal beam. The tapers are shaped as adiabatic tapers such that multiple modes are not induced.

Further modification of the embodiments described above are shown in Figs. 11 and 12. In these the full wedge shaped optical delay portion is split into a plurality of small inserts of the optical delay material. In the embodiments of Figs. 11 and 12 it will be appreciated that the optical delay material has a dn/dT of smaller magnitude (but of the same sign) as the dn/dT of the cores of the remaining portions of the waveguides. In a first version, shown in Fig.11, there are a plurality of wedge shaped inserts 40 each interrupting all the waveguides in the array. In the second version, shown in Fig.12, a plurality of inserts 42 of substantially rectangular cross-section and of different lengths are arranged generally transversely to the waveguides so as to form the shape of a wedge in the array of waveguides. The longest insert is arranged to interrupt all the array waveguides, with increasingly shorter inserts interrupting only those array waveguides with respective increasingly longer optical path length. Thus the array waveguides with the longest optical path lengths are interrupted by the greatest number of inserts.

Of course it will be understood that these inserts need not be the same width or shape as each other, and that they need not form a wedge shape. Any shape which leads to the change in optical path length of the waveguides, with change in temperature, being substantially equalized for all waveguides will suffice e.g. triangular or funnel-shaped areas.

Application No:	GB 0030258.8	**Examiner:**	Chris Ross
Claims searched:	1-23	**Date of search:**	21 March 2001

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): G2J(JGDBG)

Int Cl (Ed.7): G02B

Other: Online: WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	WO 98/39676 A1	(AN) p 2 l 1 on, p 3 l 26 on	1 at least
"	US 5799118 A	(TOSHIBA) Figs 14, 17	"

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

19. A waveguide array device substantially as described herein with reference to Figs. 5 and 8.

20. A waveguide array device substantially as described herein with reference to Figs 5. and 9.

21. A waveguide array device substantially as described herein with reference to Figs 5. and 10.

22. A waveguide array device substantially as described herein with reference to Fig. 11.

23. A waveguide array device substantially as described herein with reference to Fig. 12.

11. A device according to any of claims 1 to 9, wherein said at least one optical delay region is provided in at least one optical delay portion which comprises a core region and a cladding region, the core region being formed of a material having a dn/dT of different magnitude to, but of the same sign as, the dn/dT of the material used in the core of said at least one waveguide outside said at least one optical delay portion, for decreasing the sensitivity of the wavelength response of the device to changes in temperature.

12. A device according to claim 11, wherein the core region of said at least one optical delay portion has substantially the same dimensions as the core of the array waveguide outside the optical delay portion.

13. A device according to claim 11, wherein the core region of said at least one optical delay portion has different dimensions to the core of the array waveguide outside the optical delay portion.

14. A device according to claim 13, wherein the differently dimensioned core regions of said at least one waveguide are connected by adiabatic tapering of the core therebetween.

15. A multiplexer, demultiplexer, or multiplexer/demultiplexer comprising a waveguide array device according to any preceding claim.

16. A switch incorporating a waveguide array device according to any of claims 1 to 14.

17. A wavelength router incorporating a waveguide array device according to any of claims 1 to 14.

18. A waveguide array device substantially as described herein with reference to Figs. 5 and 7.

substantially equalizes the change in optical path length with temperature of the respective waveguide in which the optical delay region is included with at least one other said waveguide of different optical path length.

7. A device according to claim 6, wherein there is a constant predetermined difference in optical path lengths between adjacent waveguides, and said optical delay regions are provided in a wedge-shaped portion of the device, said wedge shaped portion being formed of at least one material having a dn/dT of different magnitude to, but of the same sign as, the dn/dT of the material used in the cores of the waveguides outside said wedge-shaped portion.

8. A device according to claim 7, wherein said at least one material of the wedge-shaped optical delay portion has a dn/dT of greater magnitude than the material used in the cores of the waveguides outside said wedge-shaped portion, and the wedge-shaped portion is arranged such that the widest end of the wedge-shape divides the core of the waveguide having the shortest optical length.

9. A device according to claim 7, wherein said at least one material of the wedge-shaped optical delay portion has a dn/dT of smaller magnitude than the material used in the cores of the waveguides outside said wedge-shaped portion, and the wedge-shaped portion is arranged such that the widest end of the wedge-shape divides the core of the waveguide having the longest optical length.

10. A device according to any preceding claim, wherein said at least one optical delay region is provided in at least one optical delay portion which comprises a plurality of layers made of different materials, said plurality of layers comprising a lower guiding layer and an upper cladding layer, and the guiding layer is substantially the same thickness as the core of said at least one waveguide outside said at least one optical delay portion and is made of a material having a dn/dT of different magnitude to, but of the same sign as, the dn/dT of the material used in the core of said at least one waveguide outside said at least one optical delay portion, for decreasing the sensitivity of the wavelength response of the device to changes in temperature.

CLAIMS

1. A waveguide array device comprising:

first and second optical interaction regions, each said region having a first side for input/output of an input signal/encoded output signal; and

a plurality of array waveguides connected between a second side of the first optical interaction region and a second side of the second optical interaction region, each said array waveguide comprising a core covered by cladding; wherein

the core of at least one of said plurality of waveguides includes at least one optical delay region which is made of a material having a dn/dT of different magnitude to, but of the same sign as, the dn/dT of the material used in the core of said at least one waveguide outside said at least one optical delay region, for decreasing the sensitivity of the wavelength response of the device to changes in temperature.

2. A waveguide array device according to any preceding claim, wherein said at least one optical delay region, and the cores of the waveguides in the remaining regions of the waveguides, are made of doped silica materials.

3. A waveguide array device according to claim 3, wherein the cladding of the waveguides is made of doped silica material.

4. A waveguide array device according to claim 1, wherein said at least one optical delay region, and the cores of the waveguides in the remaining regions of the waveguides, are made of polymer materials.

5. A waveguide array device according to claim 4, wherein the cladding of the waveguides is made of polymer material.

6. A device according to any preceding claim, wherein the arrayed waveguides connected between the first and second optical interaction regions have different optical path lengths, and a plurality of said array waveguides include a said optical delay region, each said optical delay region providing an optical delay which

In any of the above-described embodiments, it would alternatively be possible to design the optical delay portion(s) so as to cut though all but one of the waveguides, leaving the longest/shortest waveguide uninterrupted (depending on whether the magnitude of dn/dT of the optical delay material is greater/smaller respectively than that of the material in the remaining portions of the waveguide cores).

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